Technical Paper 62

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, Director

# RELATIVE EFFECTS OF CARBON MONOXIDE ON SMALL ANIMALS

BY

GEORGE A. BURRELL, FRANK M. SEIBERT
AND I. W. ROBERTSON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

*First edition. December, 1913.*

# CONTENTS.

Page.

Introduction .......... 5

Afterdamp .......... 6

Exposure tests with mice and canaries .......... 7

  Test with canary .......... 7

  Test with mouse .......... 8

  Sensitiveness of previously exposed mice and canaries .......... 9

    Test with canary .......... 10

    Test with mouse .......... 10

Tests with various kinds of animals .......... 11

Discussion of results .......... 13

  Symptoms exhibited by the different animals .......... 14

  Order of resistance of animals tested .......... 15

  Oxygen and carbon dioxide in the atmospheres .......... 15

  Effect of repeated exposure .......... 16

  Haldane's tests .......... 17

  Reasons for difference in results .......... 18

Practical tests of small animals .......... 19

Precautions in testing with animals .......... 20

Summary of conclusions .......... 21

Publications on mine accidents and methods of mining .......... 22

# RELATIVE EFFECTS OF CARBON MONOXIDE ON SMALL ANIMALS.

By George A. Burrell, Frank M. Seibert, and I. W. Robertson.

## INTRODUCTION.

Birds and mice are kept at the rescue stations of the Bureau of Mines in this country and at rescue stations abroad, and form part of the rescue equipment of some mines. Frequent mention of the practical use of canaries and mice in exploration work is found in technical works and in textbooks, and their usefulness at such times is well established, especially in increasing the amount of work that may be done by a rescue party with a given supply of breathing apparatus and accessories, by showing the party when such apparatus need be used. In this paper, one of a series on mine gases, are presented the results of a series of experiments conducted by the Bureau of Mines to determine the relative sensitiveness of small animals to repeated exposures to atmospheres containing carbon monoxide—a matter not previously determined by actual experiment—and the relative fitness of different kinds of small animals for use in exploration work in mines.

The results of the tests show that small animals may be repeatedly used in mines to show the presence of carbon monoxide, without danger of their losing their susceptibility to that gas, and that of the animals tested canaries are the most suitable. An additional reason for using canaries is that they are as a rule easily obtainable. They are clean and become pets of the men who have care of them. If handled intelligently they seldom die as a result of exposure to atmospheres containing carbon monoxide.

During the experiments the conditions under which recovery work with the aid of small animals must be conducted were kept in view. In such work an exploration party usually advances until the animals show signs of distress. Then the animals will in all probability be carried back to fresh air, and further advance, if such be made, will be accomplished with breathing apparatus. If a general reconnoissance is made with the animals to define the danger zone of the mine, they may be exposed at short intervals to proportions of carbon monoxide that will in each case cause collapse. Another possible contingency has to do with the use of animals in a mine atmosphere containing a very small proportion of carbon monoxide, say 0.10 per cent (a proportion that does not usually affect canaries or mice in one hour), and then in an atmosphere containing a larger proportion. It is possible, too, that an animal after collapsing at a certain place because of the proportion of carbon monoxide there may upon resuscitation be used in an atmosphere containing a proportion of carbon monoxide that does not usually affect a fresh animal, that is, one that has not been exposed a short time before. Experiments to fit this latter case were made to determine the effect on an animal of air containing a proportion of carbon monoxide that does not ordinarily affect it if it has recently been exposed to those percentages that ordinarily do affect it. Finally, the same animal may be used on several successive days while a mine is being explored.

It is believed that the experiments described in this paper cover the contingencies mentioned and show what may be expected of canaries, mice, and other animals under the conditions of rescue and exploration work in mines, and their relative suitability for use in such work.

## AFTERDAMP.

Afterdamp, which forms in a mine after an explosion or mine fire, consists principally of water vapor, smoke, carbon dioxide, oxygen, hydrogen, methane, carbon monoxide, hydrogen sulphide, and nitrogen.

Sulphur dioxide may also be present in the atmosphere and be mainly responsible for the well-known irritation of the eyes, nose, throat, and lungs. Experiments have shown sulphur dioxide to be an exceedingly noxious gas, but proportions much less than those required to produce distress in men or animals may be detected in afterdamp by the sense of smell.

Investigations by the Bureau of Mines have demonstrated that afterdamp seldom contains carbon dioxide in proportions sufficient to cause pronounced distress in men doing rescue work in mines. Hydrogen, methane, and nitrogen, as regards their physiological effects, are inert. However, a mine atmosphere may contain much nitrogen or methane, or both, and, in consequence, so little oxygen that men entering it are quickly overcome. Hydrogen sulphide is very poisonous, but its presence is easily detected by its odor.

In addition to the constituents of afterdamp that are named above there are found vapors of creosote and acetic acid, produced by the destructive distillation of coal and timber. These vapors contribute to the bituminous odor that becomes perceptible before smoke is noticed from a mine fire, and lingers in a mine long after smoke has disappeared.

Ordinarily the greatest danger to an exploration party is from the carbon monoxide, or white damp, that may be present in harmful proportions long after a smoky atmosphere has become clear and almost odorless. The most dangerous proportions of carbon monoxide are those that prevail in clear atmospheres that contain sufficient oxygen to keep the flame of a lamp burning. In such a case a lamp flame may give absolutely no indication of the presence of carbon monoxide. The bureau has records of nearly fatal results that in recent years have attended exploration work in mines in the United States in which safety lamps were the only means used to test the air. In one instance 11 men were prostrated, most of them being rendered unconscious.

## EXPOSURE TESTS WITH MICE AND CANARIES.

In order to determine how mice and canaries are affected by repeated exposure to atmospheres containing carbon monoxide, the experiments described in the following pages were performed. Bell jars having a capacity of 10 liters were used to confine the animals during exposure. The carbon monoxide used was prepared by the action of sulphuric acid on oxalic acid, the carbon dioxide produced by the reaction being removed by a solution of potassium hydroxide. At the end of one hour the breathing of the animal had at most depleted the oxygen in the atmosphere of the bell jar about 1.5 per cent, or not enough to affect the animal. The gas mixtures were mixed by a fan. Analyses of the atmospheres were made with a modified Haldane gas-analysis apparatus.[a] Ordinary temperatures and pressures were employed except where otherwise stated.

### TEST WITH CANARY.

Eight different jars were used. Exactly 0.25 per cent of carbon monoxide was added to the air in each jar and the atmosphere was then analyzed to make sure that the proportion of carbon monoxide was correct. A canary was placed in one jar and after collapse was taken out and placed in pure air. When it had seemingly regained its normal condition it was placed in a second jar containing the same proportion of carbon monoxide. This procedure was repeated until the bird had been overcome eight times. Eight successive exposures, in all probability, are more than any one bird would undergo in the course of exploration work after one disaster.

The first time the canary was exposed to the atmosphere containing 0.25 per cent of carbon monoxide it showed signs of distress in 4 minutes. When placed in pure air it seemingly recovered in 7 minutes. At each subsequent exposure 2 or 3 minutes elapsed before the bird showed signs of distress and 3 to 4½ minutes before it collapsed. During the eighth exposure it showed signs of distress in 3 minutes and collapsed in 4½ minutes. After this, the final, exposure the bird seemingly recovered in 8 minutes. The results in detail were as follows:

---

[a] Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, p. 17.

*Effect of exposing canary to atmosphere containing 0.25 per cent of carbon monoxide.*

[Date of experiment, Oct. 28, 1912.]

| Number of exposure. | Exposure began at— | Visible distress at— | Collapse at— | Recovery at— |
|---|---|---|---|---|
| | *a. m.* | *a. m.* | *a. m.* | *a. m.* |
| 1 | 10.09 | 10.12 | 10.13 | 10.20 |
| 2 | 10.20 | 10.23 | 10.24 | 10.32 |
| 3 | 10.32 | 10.33 | 10.36 | 10.44 |
| 4 | 10.44 | 10.46 | 10.49 | 10.56 |
| 5 | 10.56 | 10.58 | 11.00 | 11.07 |
| 6 | 11.07 | 11.09 | 11.11 | 11.18 |
| 7 | 11.18 | 11.20 | 11.21 | 11.33 |
| 8 | 11.35 | 11.36 | 11.37 | 11.45 |

In another test the authors once or twice daily for eight days exposed a canary to atmospheres containing 0.18 to 0.24 per cent of carbon monoxide until it collapsed. In all the exposures the time required to produce distress varied, with one exception, between 2 and 3½ minutes. In the exceptional case distress was observed in 1 minute. Collapse occurred in 3 to 10 minutes, and seeming recovery in 3 to 15 minutes. The difference in the periods of distress, collapse, and recovery could not be connected with any particular condition of the experiment. The results of this experiment were as follows:

*Results of daily exposures of canary to atmospheres containing 0.18 to 0.24 per cent of carbon monoxide.*

| Date. | Proportion of CO in atmosphere. | Exposure began at— | Visible distress at— | Collapse at— | Recovery at— |
|---|---|---|---|---|---|
| 1912. | *Per cent.* | | | | |
| October 15 | 0.18 | 1.33 p. m. | 1.38 p. m. | 1.41 p. m. | 1.48 p. m. |
| October 16 | .21 | 10.19 a. m. | ........ | 10.30 a. m. | 10.45 a. m. |
| Do | .20 | 10.56 a. m. | 10.58 a. m. | 10.59 a. m. | 11.08 a. m. |
| Do | .19 | 3.25 p. m. | 3.27 p. m. | 3.30 p. m. | 3.38 p. m. |
| October 17 | .20 | 10.10 a. m. | 10.13 a. m. | 10.15 a. m. | 10.25 a. m. |
| Do | .22 | 1.57 p. m. | 1.59 p. m. | 2.02 p. m. | 2.05 p. m. |
| October 18 | .22 | 9.33 a. m. | 9.36 a. m. | 9.38 a. m. | ........ |
| Do | .18 | 3.23 p. m. | 3.27 p. m. | 3.30 p. m. | 3.36 p. m. |
| October 21 | .20 | 10.26 a. m. | 10.28 a. m. | 10.32 a. m. | 10.37 a. m. |
| Do | .18 | 3.35 p. m. | 3.38 p. m. | 3.40 p. m. | 3.50 p. m. |
| October 22 | .20 | 9.36 a. m. | 9.39 a. m. | 9.42 a. m. | 9.50 a. m. |
| Do | .24 | 3.55 p. m | 3.56 p. m. | 4.04 p. m. | 4.05 p. m. |
| October 23 | .20 | 11.06 a. m. | 11.09 a. m. | 11.12 a. m | ........ |
| Do | .20 | 11.41 a. m. | 11.44 a. m. | 11.53 a. m. | ........ |

## TEST WITH MOUSE.

A mouse was exposed to atmospheres containing 0.30 per cent of carbon monoxide. The mouse did not evince signs of distress any more quickly after the fourth exposure than after the first. However, it did not evidence recovery so plainly as the canary. Sixteen minutes elapsed before the mouse became lively after the first exposure and 34 minutes elapsed before it became lively after the fourth. In each exposure distress was evident in 3 to 4 minutes. Collapse occurred in the first exposure after 9 minutes and in the third exposure after 7 minutes.

The detailed results of this experiment are given below.

*Effect on mouse of repeated exposures to atmosphere containing 0.30 per cent of carbon monoxide.*

[Date of experiment, Oct. 28, 1912.]

| Number of exposure. | Exposure began at— | Visible distress at— | Collapse at— | Recovery at— |
|---|---|---|---|---|
| | *p. m.* | *p. m.* | *p. m.* | *p. m.* |
| 1 | 1.46 | 1.49 | 1.55 | 2.12 |
| 2 | 2.12 | 2.15 | 2.25 | 2.48 |
| 3 | 2.48 | 2.52 | 3.04 | 3.38 |
| 4 | 3.38 | 3.41 | 3.55 | ............ |

The mouse used in the previous experiment was exposed 4 times on the following day to atmospheres containing 0.30 per cent of carbon monoxide. It showed signs of distress and collapse in practically the same periods of time as on the previous day. The results are presented below:

*Effect on mouse of exposures on second day.*

[Date of experiment, Oct. 29, 1912.]

| Number of exposure. | Exposure began at —. | Visible distress at —. | Collapse at —. | Recovery at —. |
|---|---|---|---|---|
| | *a. m.* | *a. m.* | *a. m.* | *a. m.* |
| 1 | 9.20 | 9.29 | 9.33 | 10.02 |
| 2 | 10.02 | 10.05 | 10.09 | 10.40 |
| 3 | 10.40 | 10.50 | 10.57 | 11.29 |
| 4 | 11.31 | 11.35 | 11.40 | ............ |

## SENSITIVENESS OF PREVIOUSLY EXPOSED MICE AND CANARIES.

In other experiments canaries and mice were subjected to atmospheres containing enough carbon monoxide to cause quick distress, and after revival were placed in atmospheres containing proportions of carbon monoxide that under ordinary conditions do not appreciably affect them in an hour. The object of the experiments was to determine whether after exposure to atmospheres with proportions of carbon monoxide that rather quickly produce distress, the animals would be more sensitive than ordinarily to atmospheres containing smaller proportions. The details of these experiments are presented below.

Original from PRINCETON UNIVERSITY

### TEST WITH CANARY.

A canary was placed in an atmosphere containing 0.25 per cent of carbon monoxide. After it had seemingly recovered from the effects of the exposure it was placed in another atmosphere containing the same proportion of gas, and after recovery was placed in a third. After recovery from the third exposure it was placed in an atmosphere containing 0.10 per cent of carbon monoxide. Upon each exposure to the atmosphere containing 0.25 per cent carbon monoxide the bird evinced signs of distress in 2 to 2½ minutes and collapsed in 4 to 4½ minutes. When placed in the atmosphere containing 0.10 per cent of carbon monoxide it did not show any more signs of distress in an hour than did a bird that had not been previously exposed to the gas. It exhibited only a slight weakness, which was difficult to detect. The results indicate no apparent difference, as shown by the following tabulation:

*Effect on previously exposed canary of atmosphere containing 0.10 per cent of carbon monoxide.*

[Date of experiment, Oct. 30, 1912.]

| Number of exposure. | Proportion of CO in atmosphere. | Exposure began at —. | Visible distress at —. | Collapse at —. | Recovery at —. |
|---|---|---|---|---|---|
| | *Per cent.* | *p. m.* | *p. m.* | *p. m.* | *p. m.* |
| 1 | 0.25 | 2.17 | 2.19 | 2.21 | 2.30 |
| 2 | .25 | 2.30 | 2.32 | 2.34 | 2.43 |
| 3 | .25 | 2.43 | 2.45 | 2.48 | 2.59 |
| 4 | .10 | 2.59 | (a) | ........... | ........... |

[a] Distress scarcely noticeable in one hour.

### TEST WITH MOUSE.

A mouse was placed successively in three atmospheres containing 0.30 per cent of carbon monoxide. As soon as it had recovered from one exposure it was exposed again. Finally, after the third exposure, it was placed in an atmosphere containing 0.15 per cent of carbon monoxide. In an hour's time it did not show any more distress than a mouse that had not previously been exposed to carbon monoxide. Only slight distress was noticeable. The results were as follows:

*Effect on previously exposed mouse of atmosphere containing 0.15 per cent carbon monoxide.*

[Date of experiment, Oct. 31, 1912.]

| Number of test. | Proportion of CO in atmosphere. | Exposure began at— | Visible distress at— | Collapse at— | Recovery at— |
|---|---|---|---|---|---|
| | | *a. m.* | *a. m.* | *a. m.* | *a. m.* |
| 1 | 0.30 | 9.36 | 9.40 | 9.54 | 10.13 |
| 2 | .30 | 10.13 | 10.44 | 10.54 | 11 08 |
| 3 | .30 | 11.08 | 11.30 | 11.40 | *p. m.*<br>12.03 |
| 4 | .15 | *p. m.*<br>12.03 | *p. m.*<br>[a] 1.03 | ........... | ........... |

[a] Very slight.

Original from PRINCETON UNIVERSITY

## TESTS WITH VARIOUS KINDS OF ANIMALS.

Animals other than canaries and mice have been used for exploration work in mines. Hence laboratory experiments were performed with the more common small animals other than canaries and mice. These included chickens, rabbits, pigs, pigeons, dogs, and sparrows.

In the table following are tabulated the results of the experiments—the kind of animal used; the proportions of carbon monoxide, carbon dioxide, oxygen, and nitrogen in the atmosphere; the length of time required for symptoms of distress to appear; and the length of time required for collapse to occur. In all cases, except where otherwise noted, the gas mixture was kept at the temperature of the room and at atmospheric pressure. In this work were used gas-tight containers of different dimensions, from 10-liter glass bell jars for the canaries and mice to a wooden box for larger animals. One of these boxes for the guinea pigs, rabbits, and dogs had a capacity of 200 liters (about 7 cubic feet). The atmosphere was always analyzed at the close of the experiment. In making the mixtures the calculated amount of carbon monoxide was added to pure air. The carbon dioxide content is principally from the breath of the animals. The depletion of oxygen is due to the same cause. The cause of the unusually high carbon dioxide and low oxygen content of some of the atmospheres is that in many tests the animals were exposed to atmospheres that had been used in previous experiments. In some tests carbon dioxide was purposely added to the atmosphere in the containers and in a few tests oxygen was added.

The canaries were full-grown and all of the same size. The mice were white and full-grown. The chickens were full-grown. The rabbits and guinea pigs were full-grown and of ordinary size. The dog weighed 15 pounds and was a black mongrel of uncertain breed.

*Results of carbon-monoxide tests on different kinds of animals.*

| Kind of animal. | Number of exposures. | Proportions of gases in atmosphere used. | | | | Period of exposure. | | Symptoms of distress shown in— | | Collapse occurred. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CO. | $CO_2$. | $O_2$. | $N_2$. | | | | | |
| | | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Hrs.* | *Mins.* | *Hrs.* | *Mins.* | |
| Canary | 1 | 0.10 | 0.15 | 20.85 | (a) | 3 | 50 | (b) | | No. |
| Do | 1 | .10 | .15 | 20.85 | (a) | 3 | 50 | (b) | | No. |
| Do | 1 | .10 | 1.30 | 19.60 | (a) | 1 | 30 | (c) | | No. |
| Do | 1 | .10 | 1.30 | 19.60 | (a) | 1 | 30 | (c) | | No. |
| Do | 1 | .10 | 1.30 | 19.60 | (a) | 1 | 30 | (c) | | No. |
| Do | 1 | .10 | .15 | 20.80 | (a) | 2 | 11 | | 12 | Yes. |
| Do | 1 | .10 | .72 | 20.40 | (a) | 1 | 15 | (c) | | No. |
| Do | 1 | .10 | .72 | 20.40 | (a) | 1 | 15 | (c) | | No. |
| Chicken | 1 | .10 | 1.64 | 18.65 | (a) | 2 | 45 | (c) | | No. |
| Do | 1 | .10 | .40 | 19.60 | (a) | 2 | 0 | (c) | | No. |
| Mouse | 1 | .10 | 1.30 | 19.60 | (a) | 1 | 30 | (c) | | No. |
| Do | 1 | .10 | 1.30 | 19.60 | (a) | 1 | 30 | (c) | | No. |
| Do | 1 | .10 | .15 | 20.80 | (a) | 4 | 0 | | 30 | No. |
| Do | 1 | .10 | 1.30 | 19.60 | (a) | 1 | 30 | (c) | | No. |
| Do | 1 | .10 | .10 | 20.80 | (a) | 4 | 20 | (c) | | No. |
| Do | 1 | .10 | .72 | 20.40 | (a) | 1 | 15 | (c) | | No. |
| Do | 1 | .10 | .72 | 20.40 | (a) | 1 | 15 | (c) | | No. |
| Pigeon | 1 | .10 | 5.00 | 16.90 | (a) | 1 | 40 | 1 | 35 | No. |
| Canary | 1 | .15 | .20 | 20.80 | (a) | 1 | 0 | | 30 | No. |
| Do | 2 | .15 | .20 | 20.60 | (a) | | 20 | | 12 | Yes. |
| Do | 3 | .15 | .25 | 20.55 | (a) | | 25 | | 5 | Yes.[d] |
| Do | 4 | .15 | .25 | 20.55 | (a) | | 18 | | 10 | Yes.[d] |
| Chicken | 1 | .15 | ...... | ........ | ...... | 1 | 50 | | 45 | No. |
| Small dog | 1 | .20 | 4.30 | 16.00 | (a) | 2 | 0 | (c) | | No. |
| Canary | 1 | .20 | ...... | ........ | ...... | | 12 | | 6 | Yes. |
| Do | 1 | .20 | ...... | ........ | ...... | | 13 | | 6 | Yes. |
| Do | 1 | .20 | ...... | ........ | (a) | | 13 | | 6 | Yes. |
| Do | 1 | .20 | 1.90 | 18.40 | (a) | | 40 | | 35 | Yes. |
| Do | 1 | .20 | .75 | 19.20 | (a) | | 13 | | 3 | Yes. |
| Do | 1 | .20 | ...... | ........ | ...... | | 4 | | 2 | Yes. |
| Do | 1 | .20 | .73 | ........ | ...... | | 8 | | 3 | Yes. |
| Do | 1 | .20 | 4.00 | 18.00 | (a) | | 6 | | 2 | Yes. |
| Do | 1 | .20 | 2.50 | 19.70 | (a) | | 6 | | 2 | Yes. |
| Do | 1 | .20 | 2.50 | 19.70 | (a) | | 6 | | 2 | Yes. |
| Do | 1 | .20 | .20 | 20.50 | (a) | | 6 | | 3 | Yes.[e] |
| Do | 1 | .20 | .40 | 20.30 | (a) | | 5 | | 2 | Yes.[e] |
| Mouse | 1 | .20 | 1.90 | 18.40 | (a) | | 40 | | 40 | No. |
| Do | 1 | .20 | ...... | ........ | ...... | | 40 | | 12 | No. |
| Do | 1 | .20 | ...... | ........ | ...... | | 40 | | 12 | No. |
| Do | 1 | .20 | ...... | ........ | ...... | | 40 | | 12 | No. |
| Do | 1 | .20 | .75 | 19.20 | (a) | | 24 | | 6 | No. |
| Do | 1 | .20 | .75 | 19.20 | (a) | | 24 | | 6 | No. |
| Pigeon | 1 | .20 | 1.70 | 19.60 | (a) | 1 | 15 | | 5 | No. |
| Do | 1 | .20 | ...... | ........ | ...... | 1 | 15 | | 6 | No. |
| Chicken | 1 | .20 | ...... | ........ | ...... | | 55 | | 45 | Yes. |
| Do | 1 | .20 | ...... | ........ | ...... | | 45 | | 15 | Yes. |
| Do | 1 | .20 | ...... | ........ | ...... | | 15 | | 10 | |
| Do | 1 | .20 | ...... | ........ | ...... | | 20 | | 20 | Yes. |
| Guinea pig | 1 | .20 | 8.00 | 20.00 | (a) | | 5 | (b) | | No. |
| Sparrow | 1 | .20 | .15 | 20.70 | (a) | | 55 | (c) | | No. |
| Canary | 1 | .25 | .15 | 20.69 | (a) | | 8 | | 5 | Yes. |
| Guinea pig | 1 | .25 | 2.76 | 17.50 | (a) | 4 | 10 | (c) | | No. |
| Do | 1 | .25 | 2.01 | 18.40 | (a) | 2 | 10 | (f) | | No. |
| Do | 1 | .24 | .70 | 20.30 | (a) | | 50 | | 10 | Yes. |
| Do | 1 | .25 | ...... | ........ | ...... | | 50 | | 10 | Yes. |
| Do | 1 | .27 | .72 | 19.00 | (a) | | 29 | | 22 | Yes. |
| Do | 1 | .25 | .15 | 20.80 | (a) | 2 | 7 | (c) | | No. |
| Rabbit | 1 | .25 | 2.00 | 18.00 | (a) | 3 | 20 | (c) | | No. |
| Pigeon | 1 | .25 | .52 | 20.70 | (a) | | 15 | | 10 | Yes. |
| Do | 1 | .25 | 1.45 | 18.60 | (a) | 2 | 20 | | 10 | No. |
| Do | 1 | .28 | .60 | 20.30 | (a) | | 22 | | 10 | Yes. |
| Chicken | 1 | .25 | .31 | 20.70 | (a) | | 12 | | 10 | Yes. |
| Do | 2 | .25 | .43 | 20.50 | (a) | | 10 | | 5 | Yes. |
| Do | 3 | .25 | .87 | 20.30 | (a) | | 32 | | 7 | Yes. |
| Do | 4 | .25 | 1.35 | 19.38 | (a) | | 41 | | 21 | Yes. |
| Do | 1 | .25 | 1.95 | 18.40 | (a) | | 45 | | 30 | Yes. |
| Do | 1 | .25 | .60 | 20.10 | (a) | | 40 | | 15 | Yes. |
| Dog | 1 | .25 | 1.19 | 19.70 | (a) | | 20 | | 15 | Yes. |
| Do | 2 | .25 | 4.50 | 14.80 | (a) | | 25 | | 10 | Yes. |

[a] Percentage of $N_2$ is equal to the difference between 100 and the sum of the percentages of CO, $CO_2$, and $O_2$.
[b] Slight symptoms of distress.
[c] No symptoms of distress.
[d] Temperature of atmosphere 25° C.
[e] Temperature of atmosphere 35° C.
[f] Slight symptoms of distress in 15 minutes, only slight distress in 2 hours and 10 minutes.

*Results of carbon-monoxide tests on different kinds of animals*—Continued.

| Kind of animal. | Number of exposures. | Proportions of gases in atmosphere used. | | | | Period of exposure. | | Symptoms of distress shown in— | | Collapse occurred. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CO. | $CO_2$. | $O_2$. | $N_2$. | | | | | |
| | | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Hrs.* | *Mins.* | *Hrs.* | *Mins.* | |
| Canary [a] | 1 | 0.30 | 0.30 | 70.40 | ([b]) | | 40 | ([c]) | | No. |
| Do. [a] | 1 | .30 | .30 | 70.40 | ([b]) | | 40 | ([c]) | | No. |
| Pigeon | 1 | .30 | .13 | 16.80 | ([b]) | | 40 | | 10 | Yes. |
| Sparrow | 1 | .31 | .38 | 20.50 | ([b]) | | 30 | | 5 | Yes. |
| Mouse | 1 | .34 | .13 | ........ | ...... | | 6 | | 3 | Yes. |
| Canary | 1 | .34 | .13 | ........ | ...... | | 4 | | 1 | Yes. |
| Do | 1 | .35 | .13 | ........ | ...... | | 2 | | 2 | Yes. |
| Mouse | 1 | .35 | .13 | 20.40 | ([b]) | | 6 | | 2 | Yes. |
| Guinea pig | 1 | .37 | .30 | 18.20 | ([b]) | | 12 | | 6 | Yes. |
| Do | 2 | .36 | .50 | 17.90 | ([b]) | | 15 | | 9 | Yes. |
| Do | 3 | .36 | .37 | 18.00 | ([b]) | | 15 | | 7 | Yes. |
| Do | 1 | .35 | 1.23 | 19.50 | ([b]) | | 14 | | 4 | Yes. |
| Canary [a] | 1 | .40 | .42 | 69.10 | ([b]) | | 30 | ([c]) | | No. |
| Guinea pig | 1 | .40 | .20 | 20.40 | ([b]) | | 26 | | 20 | Yes. |
| Do | 1 | .40 | .10 | 20.90 | ([b]) | | 15 | | 10 | Yes. |
| Do | 2 | .44 | .45 | 19.70 | ([b]) | | 23 | | 10 | Yes. |
| Do | 3 | .44 | .95 | 19.70 | ([b]) | | 10 | | 10 | Yes. |
| Do | 1 | .46 | 2.15 | 18.80 | ([b]) | | 3 | | 2 | Yes. |
| Do | 1 | .46 | 2.00 | 18.60 | ([b]) | | 6 | | 4 | Yes. |
| Do | 2 | .46 | 2.20 | 18.40 | ([b]) | | 5 | | 3 | Yes. |
| Do | 1 | .46 | 2.30 | 18.30 | ([b]) | | 5 | | 2 | Yes. |
| Pigeon | 1 | .48 | 3.60 | 19.03 | ([b]) | | 6 | | 3 | Yes. |
| Do | 1 | .50 | .11 | 20.80 | ([b]) | | 5 | | 3 | Yes. |
| Do | 2 | .50 | .55 | 20.20 | ([b]) | | 9 | | 4 | Yes. |
| Guinea pig | 1 | .50 | .29 | 20.80 | ([b]) | | 5 | | 2 | Yes. |
| Do | 1 | .50 | .20 | 20.80 | ([b]) | | 21 | | 9 | Yes. |
| Do | 1 | .50 | .13 | 20.90 | ([b]) | | 15 | | 7 | Yes. |
| Do | 1 | .50 | .12 | 20.80 | ([b]) | | 6 | | 2 | Yes. |
| Do | 1 | .50 | .14 | 20.80 | ([b]) | | 10 | | 5 | Yes. |
| Do. [a] | 1 | .50 | .12 | 87.60 | ([b]) | 6 | 30 | ([c]) | | No. |
| Do | 1 | .50 | 2.06 | 19.10 | ([b]) | | 10 | | 5 | Yes. |
| Do | 1 | .50 | 3.50 | ........ | ...... | | 8 | | 5 | Yes. |
| Pigeon | 1 | .56 | .38 | 20.30 | ([b]) | | 3 | | 2 | Yes. |
| Chicken | 1 | .57 | .37 | 20.30 | ([b]) | | 5 | | 2 | Yes. |

[a] Oxygen content purposely increased in this experiment.

[b] Percentage of $N_2$ is equal to the difference between 100 and the sum of the percentages of CO, $CO_2$, and $O_2$.

[c] No symptoms of distress.

## DISCUSSION OF RESULTS.

In comparing the experiments with the different kinds of small animals, it will be observed that air containing 0.10 per cent carbon monoxide affected only 1 canary out of 8 in a reasonably short space of time, namely, 12 minutes, and that 2 were only slightly affected in 4 hours. Six white mice failed to respond in 1¼ to 1½ hours, but a seventh one showed distress in 30 minutes. A chicken did not respond in 2 hours and 45 minutes.

Air containing 0.15 per cent of carbon monoxide affected 4 canaries in 5 to 30 minutes and a chicken in 45 minutes. A small dog did not show distress in 2 hours.

With a carbon monoxide content of 0.20 per cent, 12 canaries showed symptoms of distress in 2 to 6 minutes (with one exception, when 35 minutes passed before symptoms of distress were apparent); 6 mice, in 6 to 12 minutes (40 minutes in one case); 2 pigeons, in 5 and 6 minutes; and 4 chickens, in 10 to 45 minutes. A guinea pig showed slight distress in 5 minutes, and a sparrow showed no distress in 55 minutes.

With air containing 0.25 per cent of carbon monoxide guinea pigs gave variable results. Four of them showed distress in 10 to 22 minutes. One of them was only slightly affected in 2 hours, another not at all in 4 hours. A rabbit showed no distress in 2 hours and 20 minutes. Three pigeons showed distress in about 10 minutes; chickens, in 10 to 30 minutes; and a dog, in 10 to 15 minutes.

With 0.30 per cent of carbon monoxide a pigeon showed distress in 10 minutes; with 0.31 per cent, a sparrow was affected in 5 minutes.

With about 0.35 per cent of the gas in the atmosphere, 2 canaries showed distress in 1 and 2 minutes, respectively; 2 mice in 2 and 3 minutes, respectively; the same guinea pig in 4 to 9 minutes. This animal was placed back in the atmosphere as soon as it had recovered from a previous exposure. A fresh guinea pig showed distress in 4 minutes.

Air containing 0.40 per cent affected a guinea pig in 10 minutes, and another one in 20 minutes.

With 0.44 to 0.46 per cent of carbon monoxide, 4 guinea pigs showed distress in 6 exposures in 2 to 10 minutes.

With 0.50 per cent, 8 guinea pigs showed signs of distress in 2 to 9 minutes; a pigeon, in 2 and 3 minutes.

With about 0.56 per cent, a pigeon and a chicken showed distress in 2 minutes.

The above results were obtained by observing the animals' actions only, for the behavior of the animals would be the test used in exploring a mine. Blood tests would unquestionably give more consistent results. An animal may suffer some distress that only a close observer would notice, and when prodded it sometimes shifts itself so as barely to show the distress it feels.

## SYMPTOMS EXHIBITED BY THE DIFFERENT ANIMALS.

The experiments indicate that of the animals tested canaries are the most sensitive to carbon monoxide in small quantities. They sway on their perch and then fall, the symptoms being unmistakable. Mice are sluggish in their movements, and even in an atmosphere containing 0.20 per cent of carbon monoxide may not show pronounced signs of distress under 12 minutes. Some of them have a tendency to lie quiet for some time. Hence they should be prodded that they may be observed in action.

Chickens are often affected in 45 minutes by a carbon-monoxide content of 0.15 per cent. They pant, throw their heads back, stagger, and fall.

A small dog may show distress in 10 to 15 minutes in air containing 0.25 per cent of carbon monoxide. In one test with 0.15 per cent, a dog showed no distress in 2 hours. A dog affected by carbon monoxide pants, jerks its head, twitches its eyes, loses control of its hind legs, and then collapses.

Pigeons pant, stagger, and then fall. An atmosphere containing 0.20 per cent carbon monoxide causes distress in 5 minutes.

Two English sparrows that were tried were rather resistive, more so than was expected. This result was undoubtedly due to the peculiarities of the two birds tried, and does not represent the sensitiveness of the average sparrow. Strikingly inconsistent results were obtained with all of the animals tried.

Haldane[a] has shown that the time required for symptoms of carbon monoxide poisoning to appear or disappear in animals is proportional to the respiratory exchange per unit of body weight. According to their mass, sparrows should be about as sensitive as canaries. It required 5 minutes for air containing 0.31 per cent of carbon monoxide to distress a sparrow.

A guinea pig appears to show distress first by losing control of its hind legs; then it falls and rolls over on its back. A content of at least 0.25 per cent of carbon monoxide is required to affect guinea pigs in from 5 to 22 minutes.

A rabbit shows distress by breathing rapidly and jerking its head. When in a squatting position the movement of its legs is difficult to observe. Rabbits were more resistant to carbon monoxide than any of the other animals tried. With 0.25 per cent one showed no distress in about 2 hours. With 0.70 per cent 6 minutes was required.

## ORDER OF RESISTANCE OF ANIMALS TESTED.

The tests show that some animals may be much more resistant to carbon monoxide than others of the same species. Many more tests than those described here would have to be performed to obtain the true average. The weight of the animal is another factor. It is believed, however, that enough results are given in this paper to show the general behavior of the animals. According to the tests the animals rank about as follows as regards susceptibility to carbon monoxide poisoning: (1) Canary, (2) mouse, (3) chicken, (4) small dog, (5) pigeon, (6) English sparrow, (7) guinea pig, and (8) rabbit.

The sparrow is placed sixth in the above list, but as only two tests were made it is probably out of place. More tests of dogs would undoubtedly show some dogs to be more resistive than the one used.

## OXYGEN AND CARBON DIOXIDE IN THE ATMOSPHERES.

In the experiments described above most of the atmospheres used were but slightly depleted in oxygen and contained only small percentages of carbon dioxide, from the breathing of the animals. Many of the atmospheres were, according to the authors' experience, similar to atmospheres containing the given proportions of carbon monoxide, that may be found in coal mines after explosions and fires. Analyses of many such atmospheres will be published in a later report by the bureau. Experiments performed by the authors have shown that none of the atmospheres cited would distress the animals were the carbon monoxide removed. The action of the carbon monoxide is largely dependent, of course, upon the oxygen tension, but the oxygen content would have to be increased or diminished much more than the figures given indicate in order to affect the results of the experiments. As regards carbon dioxide, the quantities present were too small to produce visible effects.

---

[a] Haldane, J. S., Action of carbon monoxide on man: Jour. Physiology, vol. 18, 1895, p. 461.

The authors have subjected animals to oxygen-nitrogen atmospheres containing only 12 per cent of oxygen, also to atmospheres composed of mixtures of oxygen, nitrogen, and carbon dioxide that contained 5 per cent of carbon dioxide, without producing distress in 1 hour. These experiments were simply performed to show that to affect the result the oxygen content would have to be much lower and the carbon dioxide content much higher than in the atmospheres used in the experiments.

In some tests the animals were placed in atmospheres containing carbon monoxide and very high percentages of oxygen, with the result that the action of the carbon monoxide was hindered. Haldane[a] was the first to make this observation. He found that at a tension of two atmospheres of oxygen the poisonous action of carbon monoxide was eliminated in the case of mice.

As regards the practical use of small animals in mines, the authors recommend that canaries be used wherever possible. Mice have to be observed more closely. Pigeons and chickens may be used in an emergency, as better than nothing. In fact this may be said of all the animals, but guinea pigs and rabbits are much too resistant to be of decided value in rescue work.

## EFFECT OF REPEATED EXPOSURE.

Nasmith and Graham[b] have shown that animals finally become inured to carbon monoxide by continued exposure; that is, if a guinea pig is exposed for days or weeks to air containing small proportions of the gas it can finally stand exposures that would otherwise kill it. But in the case of animals that are for a short time exposed and quickly removed to fresh air for recovery, this effect does not take place, as far as can be observed by watching the animals. Nasmith and Graham found that in the case of guinea pigs the saturation of red blood cells by carbon monoxide was partly compensated by the formation of new cells. A similar compensation effect, varying in degree for different individuals, has also been observed in men.

---

[a] Haldane, J. S., The relation of carbonic oxide to oxygen tension: Jour. Physiology, vol. 18, 1895, p. 217.

[b] Nasmith, G. G., and Graham, D. A. L., The hæmatology of carbon monoxide poisoning: Jour. Physiology, vol. 25, 1906, No. 1, p. 32, and No. 2, p. 52.

In reading accounts of rescue and recovery work in coal mines following fires and explosions, the authors of this paper have been impressed by the fact that in some cases the use of mice and birds has not been entirely satisfactory, in that men have seemingly felt distress before the animals were affected. A case is cited by Le Neve Foster,[a] by Masterson,[b] and in an editorial in the Colliery Guardian.[c] The authors, as the result of many experiments made to determine the resistance of small animals to carbon monoxide poisoning, believe they have explanatory data. They found, for instance, that most of the animals tried did not show distress in the presence of very small percentages of carbon monoxide (less than about 0.10 per cent). In only one of the tests was a canary affected by air containing 0.10 per cent of carbon monoxide, and then in 12 minutes. In another case distress was scarcely observable after nearly 4 hours' exposure. Eight canaries were used. Six mice were then tried. One mouse was slightly affected in 30 minutes in air containing 0.10 per cent of carbon monoxide but was not overcome in 4 hours. A chicken and a pigeon were not affected. These results do not bear out Haldane's statement[d] that 0.06 per cent of carbon monoxide is sufficient to produce distinct symptoms in mice.

With 0.15 per cent of carbon monoxide canaries showed distress in 5 to 30 minutes, a mouse showed slight distress at the end of an hour. With 0.20 per cent, canaries responded in 2 to 5 minutes (with one exception, in 35 minutes) and three mice in 12 minutes. One mouse required 40 minutes.

### HALDANE'S TESTS.

Haldane[e] found that with 0.22 per cent of carbon monoxide a mouse showed distinct symptoms in 4 minutes and died in 2 hours and 25 minutes.

In further experiments to determine the relative action of carbon monoxide on men and mice Haldane[e] found that air containing 0.12 per cent of carbon monoxide distressed a mouse in 5½ minutes and caused its legs to sprawl in 11 minutes. When Haldane himself breathed the same atmosphere, he felt a slight palpitation of the heart in 33 minutes. In 90 minutes his vision and hearing were distinctly affected, and he felt a slight tendency to stagger, besides panting abnormally when he stopped the experiment long enough to run up and down stairs. In 2 hours' time vision and hearing became markedly impaired, and there was some confusion of mind, together with a throbbing headache, which, however, did not last long. The mouse, which was forced to breathe the same air during the entire experiment, could not move about after removal from the cage. It suddenly recovered while being placed in a cage 18 minutes later.

---

[a] Foster, C. Le N., and Haldane, J. S., The examination of mine air, 1905, p. 175.

[b] Masterson, John, Underground fires: Science and Art of Mining, vol. 24, 1913, p. 134.

[c] Recovery work at the Universal colliery, Senghenydd: Coll. Guard., vol. 106, Oct. 24, 1913, pp. 840–841.

[d] Haldane, J. S., The relation of the action of carbonic oxide to oxygen tension: Jour. Physiology, vol. 18, 1895, pp. 201–217

[e] Haldane, J. S., The action of carbonic oxide on man: Jour. Physiology, vol. 18, 1895, pp. 430–462.

In another experiment Haldane breathed air containing 0.027 per cent of carbon monoxide for 3½ hours. The blood saturation at the end of that time was 14 per cent. No symptoms were apparent except, perhaps, unusual shortness of breath and palpitation of the heart on running upstairs.

In another experiment with air containing 0.045 per cent of carbon monoxide no symptoms were noticed by Haldane in 4 hours during the experiment, but running upstairs caused panting and slight palpitation of the heart. A mouse was not distinctly affected.

In describing the minimum harmful or poisonous percentage of carbon monoxide Haldane [a] states that an addition of 0.05 per cent to pure air is just sufficient to produce in time slight symptoms in man and also in mice. He states that a content of 0.2 per cent is very dangerous to man.

### REASONS FOR DIFFERENCE IN RESULTS.

The differences in the results obtained by Haldane and the authors in tests with mice may be attributed to two causes: (1) Different animals of the same species may show marked differences in resistance to carbon monoxide poisoning; and (2) what may appear to be symptoms in mice to one observer may not be noticed by others.

As regards the first of the above causes, experiments described in this paper show that some animals of the same species are markedly more resistant to carbon monoxide poisoning than others. More experiments with mice and birds are outlined in this paper than Haldane records, and possibly he may not have been sufficiently impressed with the erratic indications afforded by different animals of the same species.

As to the second cause for varying results of experiments, differences in observation, the authors attempted to differentiate between any abnormal and normal appearance of the animals. At different times all three authors made the observations. As regards the birds, distress was easily seen, but not always so easily as with the mice. The value of the use of such animals in mines depends entirely on proper observation only. As the animals are often used in mines by inexperienced persons and in poor light, tests made in the laboratory offer far better conditions for observation, so that the first effects observed in mines must be more pronounced than those observed in the laboratory.

---

[a] Haldane, J. S., op. cit., p. 460.

## PRACTICAL TESTS OF SMALL ANIMALS.

In connection with the laboratory experiments described above, the authors have made observations regarding the actual use of small animals in exploration work in mines. One noteworthy instance was as follows:

A mine fire recently occurred and a sample of the mine atmosphere was obtained that contained the following constituents:

*Analysis of atmosphere in mine after fire.*

| Constitutent. | Per cent. |
|---|---|
| $CO_2$ | 1.10 |
| $O_2$ | 18.61 |
| CO | .12 |
| $CH_4$ | .42 |
| $N_2$ | 79.75 |

The sample was procured in a place where exploration work was being conducted. Canaries carried with the party were not affected by the atmosphere of the place, but two of the men finally complained of a bad headache. Later when they went to the surface they became ill. One was indisposed an entire evening.

There might have been a possibility that these men encountered gas mixtures that contained higher percentages of carbon monoxide than that shown in the analysis. There is no decisive proof to the contrary, but the authors believe that the atmosphere wherein the men worked was of fairly uniform composition. The significant fact is that the birds were with the affected persons constantly. Exploring parties without breathing apparatus should retreat toward fresh air when they feel the first symptoms of distress, such as a slight headache, and should not wait for the collapse of birds or mice to give them definite warning. Haldane [a] has shown that an atmosphere containing anything over 0.05 per cent of carbon monoxide may in time produce distinct symptoms in man. The instance cited of an actual mine exploration indicates that 0.12 per cent of carbon monoxide will do so. Experiments by the authors show that the animals tried may not be depended on to show this small percentage.

These facts, although they appear damagingly against the use of small animals for the purpose proposed, militate only in part against such use. The Bureau of Mines now has many records of their practical use in indicating bad air. Canaries will give ample warning of percentages of carbon monoxide immediately dangerous to men. They usually show distress in the presence of air containing 0.15 per

---

[a] Haldane, J. S., The action of carbon monoxide on man: Jour. Phys., vol. 18, 1895, pp. 430–462.

Digitized by Google Original from PRINCETON UNIVERSITY

cent of carbon monoxide in 5 to 12 minutes, and in air containing 0.20 per cent in 2 to 6 minutes. One of the authors breathed air with a content of 0.25 per cent of carbon monoxide for 20 minutes, and at the end of that time suffered only a slight headache, although later he became ill. The reason that small animals do not show distress when exposed to very small percentages that in time (an hour or so) affect men is not quite clear, as the blood of the animals is, of course, taking up the carbon monoxide. It is undoubtedly true that the carbon monoxide has some effect on them, although usually not to such an extent that they show pronounced distress. The reason for the deranging effect of carbon monoxide on the nervous system of some men is not well understood. This effect is in part a bar to drawing conclusions from experiments made on animals and applying them to men.

## PRECAUTIONS IN TESTING WITH ANIMALS.

In testing for vitiated air in mines with small animals, several facts must be kept in mind. The proportion of carbon monoxide taken up by the blood depends upon the quantity breathed, and under different conditions of rest or exertion, men breathe varying amounts of air. A man at rest may breathe 6 to 8 liters of air per minute. By even moderate exertion this quantity may be doubled. Consequently hard work in an atmosphere containing a given proportion of carbon monoxide may cause distress in one-half the time that would be ordinarily required. Hence the necessity of going slow. Frequently, in rescue work one or more members of the squad are affected by an atmosphere that does not disturb the others. Although this effect may without question be due to the fact that some persons are more susceptible to carbon monoxide poisoning than others, yet it may also be due to the fact that the affected men have been doing much harder work in the exploration operations, breathing more air, and as a consequence their blood has been absorbing more carbon monoxide. Also, it may be that the men affected have breathed a more vitiated atmosphere than the other men or the animals used.

Although on the whole different mice or birds, when placed in an atmosphere containing a given proportion of carbon monoxide, evince distress in about the same time, yet the experiments outlined show that once in a while an animal may be much more resistant than was expected. This is more true of mice than canaries, yet even in the case of canaries at least three should be taken into a mine with a party.

Both men and animals can breathe without discomfort atmospheres containing percentages of oxygen below that in which an oil flame goes out (about 17 per cent). In fact the oxygen content may be as low as 12 per cent before affecting either men or animals, at least in a comparatively short time; hence, if electric lamps are at hand, no alarm need be felt by a party if oil lamps go out, so long as the animals show no distress. The extinction of the flame then indicates that the oxygen content is low and not that carbon monoxide is present.

Upon collapse, canaries or mice can be quickly revived if removed to fresh air, but they may succumb rather quickly if not soon revived, especially canaries. Some disadvantage in the use of birds lies in the fact that their sudden collapse may deprive a party of their use. In such a case the members of the party should retrace their steps to pure air.

## SUMMARY OF CONCLUSIONS.

In testing for gas in mines small animals may be used repeatedly without danger of their being less susceptible to carbon-monoxide poisoning after many exposures than after the first, if they are allowed to recover between exposures.

Canaries are less resistant to carbon-monoxide poisoning than mice, chickens, rabbits, guinea pigs, or dogs. It is recommended that canaries be used whenever possible and that at least three of them be carried by an exploration party.

Men may display distress in the presence of proportions of carbon monoxide as small as 0.10 per cent, whereas small animals in the same atmosphere may show no signs of being affected.

## PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF MINING.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls., 4 figs.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 106 pp., 2 pls., 23 figs.

BULLETIN 44. First national mine-safety demonstration, Pittsburgh, Pa., October 30 and 31, 1911, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine by G. S. Rice. 1912. 75 pp., 7 pls., 4 figs.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1913. 50 pp.. 3 pls., 7 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 56. First series of coal-dust explosion tests in the experimental mine, by G. S. Rice, L. M. Jones, J. K. Clement, and W. L. Egy. 1913. 115 pp., 12 pls., 28 figs.

BULLETIN 62. National mine-rescue and first-aid conference, Pittsburgh, Pa., September 23–26, 1912, by H. M. Wilson. 1913. 74 pp.

BULLETIN 65. Oil and gas wells through workable coal beds; papers and discussions, by G. S. Rice, O. P. Hood, and others. 1913. 101 pp., 1 pl., 11 figs.

BULLETIN 69. Coal-mine accidents in the United States and foreign countries, compiled by F. W. Horton. 1913. 98 pp., 3 pls., 40 figs.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp., 1 fig.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp., 11 figs.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The prevention of mine explosions, report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 22. Electrical symbols for mine maps, by H. H. Clark. 1912. 11 pp., 8 figs.

TECHNICAL PAPER 23. Ignition of mine gas by miniature electric lamps, by H. H. Clark. 1912. 5 pp.

TECHNICAL PAPER 24. Mine fires, a preliminary study, by G. S. Rice. 1912. 51 pp., 1 fig.

TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 6 pp.

TECHNICAL PAPER 30. Mine-accident prevention at Lake Superior iron mines, by D. E. Woodbridge. 1913. 38 pp., 8 figs.

TECHNICAL PAPER 33. Sanitation at mining villages in the Birmingham district, Ala., by D. E. Woodbridge. 1913. 27 pp., 1 pl., 9 figs.

TECHNICAL PAPER 40. Metal-mine accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 54 pp.

TECHNICAL PAPER 43. The influence of inert gases on inflammable gaseous mixtures, by J. K. Clement. 1913. 24 pp., 1 pl., 8 figs.

TECHNICAL PAPER 44. Safety electric switches for mines, by H. H. Clark. 1913. 8 pp.

TECHNICAL PAPER 46. Quarry accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 32 pp.

TECHNICAL PAPER 47. Portable electric mine lamps, by H. H. Clark. 1913. 13 pp.

TECHNICAL PAPER 48. Coal-mine accidents in the United States, 1896–1912, with monthly statistics for 1912, compiled by F. W. Horton. 1913. 74 pp., 10 figs.

TECHNICAL PAPER 52. Permissible explosives tested prior to March 1, 1913, by Clarence Hall. 1913. 11 pp.

TECHNICAL PAPER 53. Proposed regulations for the drilling of gas and oil wells, with comment thereon, by O. P. Hood and A. S. Heggem. 1913. 28 pp., 2 figs.

TECHNICAL PAPER 59. Fires in the Lake Superior iron mines, by Edwin Higgins. 1913. 34 pp., 2 pls.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp., 5 figs.

MINERS' CIRCULAR 5. Electrical accidents in mines, their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.

MINERS' CIRCULAR 7. The use and misuse of explosives in coal mining, by J. J. Rutledge, with a preface by J. A. Holmes. 1913. 52 pp., 8 figs.

MINERS' CIRCULAR 8. First-aid instructions for miners, by M. W. Glasgow, W. A. Raudenbush, and C. O. Roberts. 1913. 66 pp., 46 figs.

MINERS' CIRCULAR 9. Accidents from falls of roof and coal, by G. S. Rice. 1912. 16 pp.

MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1912. 14 pp.

MINERS' CIRCULAR 11. Accidents from mine cars and locomotives, by L. M. Jones. 1912. 16 pp.

MINERS' CIRCULAR 12. The use and care of miners' safety lamps, by J. W. Paul. 1913. 16 pp., 4 figs.

MINERS' CIRCULAR 13. Safety in tunneling, by D. W. Brunton and J. R. Davis. 1913. 19 pp.

MINERS' CIRCULAR 15. Rules for mine-rescue and first-aid field contests, by J. W. Paul. 1913. 12 pp.

○